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Operation of Silicon Microstrip Detectors in a High Radiation Environment *

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Abstract

A Silicon Microstrip Spectrometer was recently installed and operated in an 800 GeV proton beamline at Fermilab as a major new component of experiment E789. The detectors received an estimated radiation exposure of up to 7.8×10^{12} minimum ionizing particles per cm^2 over a period of two months. We report on the changes in detector performance that we have observed following preliminary data analysis.

Introduction

Silicon microstrip detectors are a major new component of Fermilab fixed target experiment E789, designed to study the rare decays of the B and D mesons in a high radiation environment. During a recent test run, ten detectors were installed in the 800 GeV proton beamline for E789. The detectors are positioned five above, and five below the beam axis. The innermost strips of the up and down arm of the Spectrometer are located at an angle of 20 mrad from the target relative to the beam axis. The detector plane that is farthest upstream, YS1, is 40 cm downstream of the target, and 8 mm above the beam. Strip rates were monitored at several locations on the YS1 detector. The target related beam rate at YS1 varied by a factor of three across the first 400 strips. Beam monitoring was precise for the data runs, but not for additional beam exposure during setup and calibration. The total integrated beam intensity is known to about 15%. We estimate the total local integrated flux from the measured rates at YS1 to be 7.8×10^{12} minimum ionizing particles per cm^2, (195 KRad), at the innermost strips.

Detectors

The E789 silicon detectors were manufactured by Micron Semiconductor. They are single-sided N-type detectors with ion implanted P-type strips. The silicon wafers are 300 microns thick, and 5 cm x 5 cm in area. The strips are oriented horizontally. The strip pitch is 50 microns. The strips are fanned out on a printed circuit board and dc coupled to custom designed fast preamplifiers[1]. The amplified signals are discriminated and latched. No pulse height information is recorded.

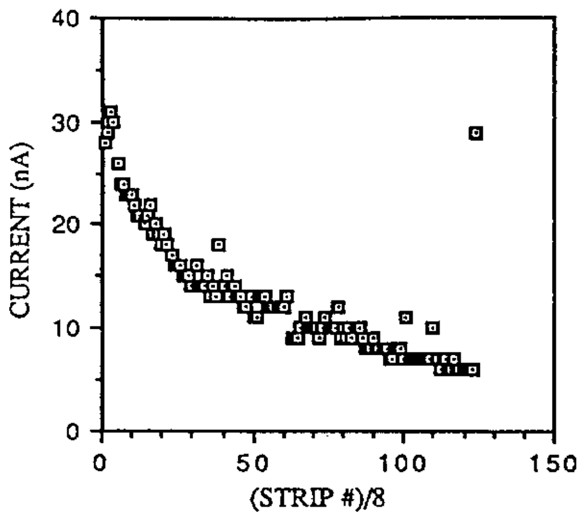

Figure 1. Strip current across YS1T.

Leakage Current

Prior to installation, the leakage current was measured for each detector at it's full depeletion voltage. The total current for a single detector before beam exposure was typically 1 µA. Individual strip currents were mostly uniform across the detector. The typical voltage required to fully deplete the detectors was 35V.

Individual strip currents for the YS1 detector are shown in figure 1. The data were recorded 18 days after the last beam exposure. In a previous radiation damage study performed at the Los Alamos Meson Physics Facility[2], (LAMPF), in a 0.8 GeV proton beam, we measured a damage constant, (α), for bulk generation current of 1.8×10^{-17} A/cm. Using this value for α, a strip current of 30 nA, and the relationship, $I_{leak} = \alpha$ F, the local fluence, (F), we derive for the innermost strips of YS1T is $5.6 \times 10^{12}/cm^2$. The discrepancy between this estimate and the estimate based on scaler rates might be explained by short term annealing occuring during beam down periods.

The reverse bias current vs bias voltage characteristic, (I/V), from four of the detectors, as measured 11 days after the run, is shown in figure 2. The total current has increased by more than a factor of 20 on each of the detectors. With the exception of the detector that is labeled YS4B, the detectors exhibit good diode characteristics. The detector YS4B is a prototype that required much rework to the printed circuit fanout board to repair shorts and open circuits. The strip current profile that we measure does not match the beam intensity across this detector. We see clusters of high leakage current that are distributed across the wafer. These hot spots exhibit a linear dependence on bias voltage and dominate the I/V characteristic. Either the wafer was initially defective or surface damage was incurred during the repair.

Figure 3 shows the same I/V characteristics measured 25 days after the run. There is clear evidence that the detectors are annealing. The average decrease in leakage current for all 10 detectors is 32% in 25 days.

The I/V characteristics also suggest that the voltage at which the detectors are fully depleted is lower than the initial 35V. A decrease in depletion voltage is consistent with acceptor site creation in the N-type bulk of the silicon, as has been described by Dietl et al.[3]. A recent study by Ziock[4] indicates a damage rate, (β), for acceptor site creation of β =.066/cm. The E789 detectors have an initial dopant concentration of approximately 5×10^{11} donors per cm^3. If we assume that the average fluence across an entire detector was $4.9 \times 10^{12}/cm^2$, and use the value for β of .066/cm, then more than 50% of the initial donor sites have been effectively replaced by acceptors in that detector. Depletion voltage is proportional to the donor concentration[5], and can

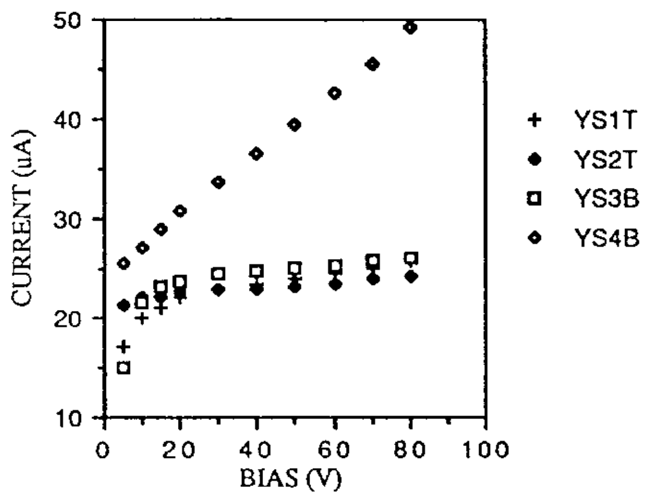

Figure 2. I/V charateristic, 11 days after irradiation.

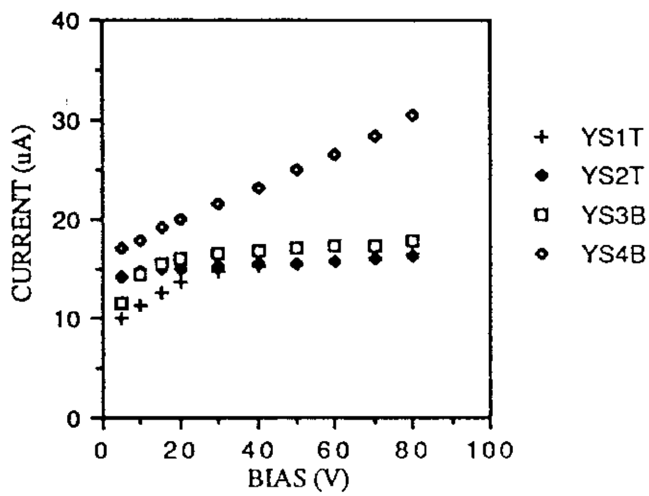

Figure 3. I/V characteristic, 25 days after irradiation.

be approximated by :

$$V_d = (q \cdot N_d \cdot d^2) / 2\varepsilon, \quad (1)$$

where V_d is the depletion voltage, q is the unit electron charge, N_d is the donor concentration, d is the wafer thickness, and ε is the dielectric constant for silicon. The damage to the E789 detectors, however, is not uniform across the detector. The areas of the detector that have received the most damage should be depleting at lower voltages than other less damaged regions. Figure 4 is the I/V characteristic for three strips from detector YS1B. Strip 16 is closest to the beam, and therefore has received the most damage of the three. The current plateau for strip 16 occurs at about 10V, compared to about 20V for the other two, indicating that it is depleted at a lower voltage.

During the run, with beam on, detector currents increased well above 100 μA. This very high value of current would decrease rapidly after turning the detectors off for several hours. In the LAMPF study we observed similar detector behavior, and attribute this component of the total current to surface current.

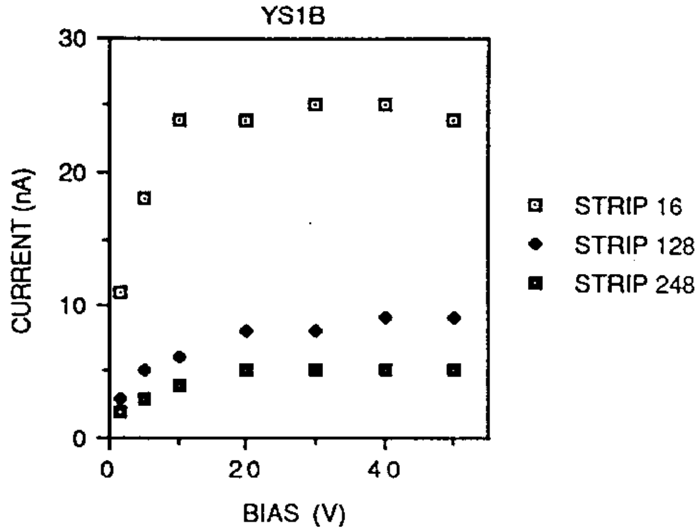

Figure 4. The I/V characteristic for three strips from detector YS1B. Strip 16 is closest to the beam.

Detector Performance

Preliminary results indicate that the Silicon Spectrometer performance is good. The silicon enables us to construct a target profile from a 200 micron wire target with a sigma of 100 microns. The sigma of the residual distribution for the location of tracks in the silicon is 14 microns.

Approximately 10% of all tracks in the silicon fire adjacent strips. There is no evidence thus far that the level of charge sharing has changed with detector damage.

The detector bias voltages were all initially set at 40V. We measured the detector efficiencies on-line to have an average value of 90%. After about 40 days of beam time detector efficiciencies fell by about 10%. In order to restore good efficiency it was necessary to raise the bias voltage. Since the voltage required to deplete the detectors had decreased, we conclude that the increased electric field in the detector reduced the effects of charge trapping. For the remainder of the run, we operated the detectors at 80V. A sharp reduction in strip pulse height was observed during the previous LAMPF study, and occured between 5.5×10^{12} and 1.4×10^{13} protons/cm^2. This loss in amplitude was also recovered by raisng the bias voltage.

Conclusion

The damage effects of ionizing radiation on silicon microstrip detectors include increased leakage current, and the creation of acceptor sites in the bulk of the silicon. Acceptor sites initially lower the voltage required to fully deplete the detector. In addition, acceptor sites cause a loss of charge collection efficiency due to trapping. Increasing the electric field strength within the detector can restore efficiency.

References

[1] D. Christian et al., " The Development of Two ASIC's For A Fast Silicon Strip Detector Readout System," IEEE Trans. on Nucl. Sci., NS-36, 507-11, (1989).

[2] C.S. Mishra et al., 15th APS Division of Particles and Fields General Meeting (DPF-90), Fermilab Conf. 90/107, Houston, Texas, January 3-6, 1990.

[3] H. Dietl et al., " Radiation Damage in Silicon Detectors," Nucl. Instr. and Meth., A253, 460-66, (1987).

[4] H. Ziock, private communication.

[5] E. Gatti, " Processing the Signals From Solid-State Detectors in Elementary-Particle Physics," Revista Nuovo Cimento, Vol. 9, No. 1, 1-146, (1986).